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Planetary Protection Implementation on Future Mars Lander Missions

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FOREWORD

This is the final report of the joint U.S./Russian Workshop on Planetary Protection Implementation for Future Mars Lander Missions that was hosted by NASA Ames Research Center and convened in July 1992. The format of the workshop included a series of invited talks on topics relevant to the workshop objectives (see Appendix 2 for a list of topics and presenters), a discussion session, and the development of conclusions and recommendations. The same format is followed in this final report.

At the time of the workshop, the Space Studies Board's (SSB) report on biological contamination of Mars was in press. The two main recommendations from that study were known and discussed at this workshop. Many of the recommendations of this workshop bear directly on interpretation of that report. No attempt, however, has been made to incorporate into this document the details of that study, which subsequently became available with the publication of the SSB report.

Since the time of the workshop, the Mars Environmental Survey (MESUR) Pathfinder and MESUR Network mission design concepts have undergone some change. For this report, they are described as they existed at the time of the workshop. Subsequent changes in those missions have had no effect on the conclusions reached by this workshop.

It is hoped that the results of this workshop will be useful to planetary protection policy makers and Mars mission planners in the international community as various space agencies and Committee on Space Research (COSPAR) finalize planetary protection policy and requirements for future Mars lander missions.

The final section of this report, Other Topics, includes a brief summary of some of the issues expected to be important for planning Mars sample return missions. This preliminary discussion was in preparation for the next joint U.S./Russian workshop, which will be held on the subject of planetary protection issues and Mars sample return missions.

ABSTRACT

A workshop was convened to discuss the subject of planetary protection implementation for Mars lander missions. It was sponsored and organized by the Exobiology Implementation Team of the U.S./Russian Joint Working Group on Space Biomedical and Life Support Systems. The objective of the workshop was to discuss planetary protection issues for the Russian Mars '94 mission, which is currently under development, as well as for additional future Mars lander missions including the planned Mars '96 and U.S. MESUR Pathfinder and Network missions.

A series of invited presentations was made to ensure that workshop participants had access to information relevant to the planned discussions. The topics summarized in this report include exobiology science objectives for Mars exploration, current international policy on planetary protection, planetary protection requirements developed for earlier missions, mission plans and designs for future U.S. and Russian Mars landers, biological contamination of spacecraft components, and techniques for spacecraft bioload reduction. In addition, the recent recommendations of the U.S. Space Studies Board (SSB) on this subject were also summarized.

Much of the discussion focused on the recommendations of the SSB. The SSB proposed relaxing the planetary protection requirements for those Mars lander missions that do not contain life detection experiments, but maintaining Viking-like requirements for those missions that do contain life detection experiments. The SSB recommendations were found to be acceptable as a guide for future missions, although many questions and concerns about interpretation were raised and are summarized in this report. Significant among the concerns was the need for more quantitative guidelines to prevent misinterpretation by project offices and better access to and use of the Viking data base of bioassays to specify microbial burden targets. Among the questions raised were how will the SSB recommendations be integrated with existing Committee on Space Research (COSPAR) policy and how will they apply to and affect Mars '94, Mars '96, MESUR Pathfinder, and MESUR Network missions?

One additional topic briefly considered at the workshop was the identification of some issues related to planetary protection considerations for Mars sample return missions. These issues will form the basis for a follow-on joint U.S./Russian workshop on that subject.

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INTRODUCTION

This workshop, entitled Planetary Protection Implementation on Future Mars Lander Missions, was convened by NASA Ames Research Center and was held in Palo Alto, California, on July 13–15, 1992.[1] It was an official activity of the Exobiology Implementation Team (EIT) of the U.S./Russian Joint Working Group on Space Biomedical and Life Support Systems.[2] The workshop was co-chaired by Dr. Donald L. DeVincenzi, Ames Research Center, and Academician Mikhail V. Ivanov, Russian Academy of Sciences. Workshop participants included leading experts in the field of planetary protection and individuals and organizations representing an engineering and scientific cross section of groups affected by planetary protection implementation (see Appendix 1 for a list of workshop participants).

The purpose of the workshop was to facilitate U.S. and Russian bilateral discussions on planetary protection implementation for future Mars lander missions. These discussions were not intended to establish joint policy on, or requirements for, planetary protection, but rather to identify options available to satisfy Committee on Space Research (COSPAR) recommendations and the additional research needed to achieve various options. The workshop was timely, considering the Russian launches for Mars planned for 1994 and 1996 and the U.S. Mars Environmental Survey (MESUR) Pathfinder mission currently under study. Additionally, this subject becomes increasingly important as interest in the Space Exploration Initiative (SEI) and planning by U.S. and Russian scientists for robotic Mars life detection and sample return missions continues.

Workshop presentations and discussions were oriented to achieve a common level of scientific and program knowledge, to summarize the current status of planetary protection implementation methodology and scientific requirements, and to identify gaps in our knowledge and technology requiring additional studies.

Although the U.S. Viking missions provided significant experience on implementing planetary protection requirements, more recent information about the Mars environment and terrestrial biology warrants a continuing evaluation of planetary protection requirements and implementation methodology. Two recent activities along these lines were the NASA Ames Research Center Workshop on Planetary Protection Issues for the MESUR Mission: Probability of Growth (P_g) (NASA Conference Publication 3167, H. P. Klein, editor, 1992) and the National Academy of Sciences, Space Studies Board Report on Biological Contamination of Mars (National Academy Press, 1992).

It was noted that in the past less work was conducted on planetary protection in the former Soviet Union than in the United States, and in the 1970s planetary protection technology was developed to a greater degree in the United States. Recently, the situation in Russia has changed and there is now an increased interest in these issues. This has resulted in various proposals being developed relating to planetary protection requirements and their implementation on Russian

[1] Ames Research Center is the NASA lead center for exobiology and home of NASA's Center for Mars Exploration. Ames also has long-standing involvement and experience in planetary protection policy and implementation.

[2] In addition to planetary protection activities, the EIT sponsors studies, meetings, and/or research in areas of Earth orbiting spacecraft useful for exobiology, search for extraterrestrial intelligence, scientist exchanges, joint field work, joint Mars missions, and Mars exploration sites of interest to exobiology.

missions. The discussions and joint recommendations from this workshop should be useful for the planning of Russian Mars missions scheduled for launch in 1994 and 1996 and to future COSPAR deliberations on planetary protection policy.

An additional subject for discussion at the Workshop dealt with the scientific, technological, and social issues associated with Mars sample return missions. Although there are no concrete plans for sample return missions in Russia or the United States, it is not too early to start considering planetary protection issues, since planetary protection measures for sample return missions will require a greater effort to execute.

A preliminary report of this Workshop was discussed at the EIT meeting held prior to the COSPAR and World Space Congress meetings in August 1992 in Washington, D.C. Although this workshop was organized as a bilateral effort, the international flavor of future Mars missions suggests that future meetings on this subject be multinational in scope.

BACKGROUND

This section contains short summaries of each of the presentations made at the workshop (see Appendix 2 for list of presenters). The materials used to illustrate the presentations are available upon request from the authors.

Ancient Life/Chemical Evolution on Mars

The basic biochemical properties of living systems suggest that there is a common ancestry of life on Earth. This ancestry can be used as a guide for the search for early life forms on Mars. Comparisons between environmental conditions on early Earth and early Mars show similarities that are considered to be important for the origin of life on both planets. The search for fossils on Mars is of particular relevance to planetary protection because it deals with the possibility that life may have arisen on Mars at some time in the past. Research within the past 15 years supports this possibility. Comparisons between the environments of early Earth and early Mars were made and it appears that the early environment on Mars may have been conducive to the origin of life. Evidence was offered that the factor most important for the timing of the origin and survival of life was impact of meteorites. Life on Earth may have begun in less than a one-half-billion-year window. It is conceivable that life on Mars may not have required an inordinately long period to develop either and, consequently, a study of the early history of Mars is exceedingly important.

Key features for site selection on Mars in searching for ancient life were also discussed. Certain sites were identified as important because they are thought to have had the potential to promote the development of life and provide a means to preserve fossils. Advantages and disadvantages of various site types were discussed. For example, evidence was presented that sites possessing some of the important criteria (e.g., evidence of liquid water in the past) have already been observed on Mars, and photographic evidence suggests that several other environmental properties important for the formation of life existed at one time in the planet's history.

There are several advantages to a strategy that focuses on the search for fossil life, including exploration of the history of Mars and, by extrapolation, of the solar system itself; exploration of an ancient interval on the planet that may have been more favorable for the formation of life; enhancement of the sensitivity with which we might detect evidence for ancient life; and elucidation of the origin of life on Earth since it may be possible that preservation of fossil life on Mars may be improved over that on Earth.

Extant Life on Mars

Strategies for searching for living organisms on Mars were reviewed and were based on looking for organic substances in the surface layers of the soil and detecting the presence of heterotrophic and photoautotrophic microorganisms in the Martian soil in the near-equatorial region where there might be daily temperatures above freezing and perhaps periods of liquid water. Data from the Viking mission, however, demonstrated no evidence for these conditions or the presence of life forms. Furthermore, Viking provided data indicating the presence of environmental conditions that are not conducive to the presence of life, namely, a high level of ultraviolet (UV) radiation, an extremely low level of moisture in the atmosphere, the absence of organic substances in the surface layers, sharp fluctuations in daily temperatures, and the presence of chemically active peroxide compounds that may be toxic to microorganisms.

Following Viking, some scientists became extremely pessimistic about the possible presence of extant life on Mars and proposed to focus more attention on past or extinct life forms. However, several exobiologists remained optimistic and proposed further emphasis on the search for extant life, particularly in the subsurface soils of Mars, where there might be organic material and protection from lethal UV radiation. Additionally, organisms could occur in resting forms (e.g., spores) in or near the polar caps or permafrost of Mars. Antarctic research indicates the existence of photoautotrophic, cryptoendolithogenic microorganisms living in conditions that might mimic some Martian environmental conditions.

Therefore, a new strategy was proposed for the search for microorganisms on Mars that concentrates on searching for aerobic and anaerobic chemolithoautotrophic bacteria. This strategy is recommended because these organisms do not need a readily available source of organic material but can fix carbon dioxide as their only source of carbon.

It was recommended that primary mission landing site selection should concentrate on areas on Mars that indicate possible residual hydrothermal activity and where flows of reduced gases, water vapor, and other critical elements from the interior may exist. Although no such sites on Mars have been identified to date, the search for these sites should be a focus of future missions. Studies at such sites should include both surface and subsurface properties. Experiments should include measurements of pH and Eh and isotopic evaluations of sulfur, carbon, and hydrogen. Recent geochemical literature was cited that provides evidence that is consistent with the existence on Mars of subsurface environments favorable for possible anaerobic chemolithoautotrophic microorganisms. Meteorite analyses and laboratory experimentation were also presented to support the theory that environmental conditions or sites exist on Mars which are capable of supporting the presence of metabolic processes similar to those used by chemolithoautotrophic microorganisms.

Existing NASA/COSPAR Planetary Protection Policy

The current basic statement of planetary protection policy adopted by NASA is formulated to preserve science; meet signatory treaty agreements on the protection of planets, including the Earth, from potential hazards; and protect the planets by imposing controls on potential contamination carried by space vehicles. The NASA policy is contained in NASA Management Instruction (NMI) 8020.7C. The policy applies to all missions to the planets and return missions to Earth; however, the actual controls imposed on a given mission are based on the mission objective, the target planet under investigation, the current knowledge base existing at the time of launch, and recommendations from scientific groups such as the Space Studies Board (SSB) of the National Academy of Science (NAS). U.S. planetary protection policies, procedures, regulations, and guidelines are prescribed by NASA's Planetary Protection Officer (PPO). Additionally, the PPO is responsible for certifying compliance with the established policies and guidelines, and individual projects are compelled to demonstrate compliance with this policy.

Current NASA and COSPAR policies, which were developed in 1984 (D. L. DeVincenzi and P. D. Stabekis: Revised Planetary Protection Policy for Solar System Exploration. Adv. Space Res., vol. 4, no. 12, 1984, pp. 291–295), divide mission/target planet combinations into five categories. Category I applies to planets where planetary protection is not required. Category II applies to planets where there is no concern about biological contamination per se, but where there is a desire to minimize organic contamination and its impact on future understanding of exobiological data. Category III applies to planets where contamination concerns exist, but there is no mission requirement for the spacecraft to contact the planet. Category IV is the same as Category III with the exception that the mission is designed for spacecraft to come in contact with the planet. (A mission designed to land a spacecraft on the surface of Mars would be a Category IV mission. Because of biological interest in Mars, a Category IV classification would apply even if there were no concern about terrestrial life growing on Mars. It should be noted, however, that the implementation techniques might be modified.). Category V applies to sample return missions from another planet to Earth. Therefore, the constraints applied to a specific mission depend greatly on the type and destination of the mission and become increasingly more rigorous for higher category missions.

The Magellan and Galileo missions have used this planetary protection approach. Both were classified as Category II missions. These missions required or will develop and submit pre- and post-launch documentation and reports at the completion of the mission on the fate of the spacecraft. Planetary protection guidelines for Mars Observer are described in a later section of this report.

Space Studies Board Recommendations

A recent study conducted by the SSB of the NAS at the request of NASA Headquarters was discussed. The final report was published after this workshop was held (see reference on page 1).

The starting point for the SSB study was the 1978 Space Science Board's reevaluation of planetary protection policy and state of knowledge of planetary properties. The recent study focused only on forward contamination. No efforts were spent on addressing back contamination issues. The SSB did not attempt to assign a mathematical value to the probability of growth of a terrestrial

organism on Mars. However, the study group believed that the likelihood of a terrestrial organism growing on Mars is extremely remote and that assigning a value seemed meaningless.

The SSB report recommends that landers carrying instrumentation for in situ investigation of extant life should be subjected to at least Viking-like bioload reduction procedures. They recommended that sterilization technology developments over the past 15 years be evaluated for their applicability to spacecraft. The SSB stated that landers and orbiters without biological experiments should be subjected to special cleaning and assembly procedures, and bioload levels should be reduced to a level equal to or less than the bioload level for Viking prior to terminal dry heat treatment. They further noted, however, that the nature of the instrumentation and the properties of the sites to be explored should play a part in the burden reduction requirements. Microbial detection techniques have improved since Viking and the recommendation was made that procedures should be evaluated for their applicability to burden assessment on a spacecraft.

In the ensuing discussion, various interpretations of the SSB's recommendations were offered. Several participants noted the absence of quantitative targets in the recommendations and were concerned that insufficient definition would make it more difficult to identify the procedures needed for implementation. Others felt that the use of the terms "Viking" or "Viking-like" implied a quantitative level. Several participants suggested that the term "life detection experiments" be defined and asked if the recommendation implied that vehicles containing instrumentation looking for elements associated with life would also require bioload reduction. The SSB report contains a much more detailed description of the recommendations and also contains the data and references that were used to substantiate the recommendations.

Planetary Protection Implementation for Viking Orbiters

The objectives of the Viking mission were reviewed. A graphic representation of the mission profile, Viking Orbiter (VO), and Viking Lander (VL) was shown, and the steps taken to achieve planetary protection requirements were identified. COSPAR recommendations and NASA constraints imposed on Viking were presented in detail and accompanied by a summary of the probabilistic approach used to establish compliance with the imposed constraints. For the VO, these constraints translated into cleanroom assembly, biological burden limitations at launch, trajectory biasing requirements, and orbit lifetime constraints. Implementation technology was discussed in detail.

Planetary Protection Requirements for Mars Observer

Mars Observer (MO) is the first mission to Mars since Viking. Therefore, it is the first Mars mission required to comply with the 1984 planetary protection policy revisions. In arriving at the appropriate categorization for the mission, NASA requested that the SSB review the mission and mission objectives and make appropriate recommendations. After a thorough review, the SSB recommended the MO mission be designated as a Category III mission. The SSB further recommended that the MO project implement cleanroom assembly (Class 100,000), bias the injection aim point of the spacecraft to assure a probability of $<10^{-5}$ of impact of the launch vehicle and a

probability of $<10^{-4}$ of impact of the spacecraft, select a mapping orbit such that the probability of remaining in orbit until the year 2009 is >0.9999, and raise the orbit sufficiently upon completion of the nominal mission to ensure that the probability of stable orbit is >0.95 until the year 2039.

These recommendations were adopted by NASA and imposed on the MO project. The project converted these constraints into project requirements and determined the appropriate mission designs required to achieve the requirements. The formalized implementation plans were documented in a planetary protection plan approved by NASA's PPO. Selected data were presented to the workshop, from an MO project briefing held on May 19, 1992, which demonstrated compliance of the mission. In summary, the project indicated the probability of impact of the launch vehicle is $<10^{-5}$, the probability of the spacecraft impacting Mars before 2009 is 4.4×10^{-5}, and the probability of impact between the year of 2009 and 2039 is 8×10^{-3}. These conditions are achieved by controlling the periapsis altitude to >325 km. It was also noted that both contractor and launch site facilities used for assembly and test activities employ Class 100,000 cleanrooms. So, all imposed planetary protection requirements were implemented and the SSB recommendations were achieved.

During the discussion, questions were raised regarding the validity of comparing MO planetary protection requirements with those for the VO. The controls were qualitatively the same, but actual specifications were mission specific and consequently differed quantitatively. It was also noted that the orbit lifetime requirements for MO were extended beyond those imposed on Viking. Additional discussions were related to how much of the vehicle would be assembled in a cleanroom environment and whether such requirements apply to the components, the total vehicle, or both. Although there might be some components or subassemblies exposed to levels exceeding Class 100,000, most electronic and spacecraft assembly and test facilities used in the U.S. aerospace business were equal to or better than Class 100,000.

Planetary Protection for Viking Landers

The planetary protection measures implemented for the VL were summarized. This included the analyses that dictated the requirement for bioload reduction and protection against recontamination. Implementation procedures used to achieve the required levels of bioload reduction were presented along with several of the technical parameters provided to the Viking Project (VP) by NASA. These parameters were needed for calculating the duration and temperature exposure for component and vehicle heating.

The thermal models, test vehicles, analyses, and temperature regimes were also presented in some detail. This was followed by a description of the actual terminal heating process used for the two VLs and a detailed summary of recontamination prevention measures that were implemented. Also presented was the calculated probability of contamination for each Viking lander that demonstrated consistency with the planetary protection requirements and constraints imposed on the VP. The measures implemented to achieve planetary protection mission requirements included lander cleanroom assembly, surface cleaning to reduce burden levels, bioassay of the vehicles, bioload reduction of the landers using dry heat, lander recontamination prevention including encapsulation in a bioshield, monitoring of burden levels on the VO and nose fairing, trajectory biasing of the

launch vehicle and spacecraft including deflection of the launch vehicle, and minimum altitude requirements for the VO and bioshield base, as well as many others.

MESUR Pathfinder Mission Design and Planetary Protection Issues

The concept for the 1996 MESUR Pathfinder mission, including a description of the estimated project costs, planned launch date, science payload, and other mission objectives, was presented. The Pathfinder mission would be a single spacecraft launched on a Delta II vehicle in late 1996, with arrival at Mars in November 1997. The mission is planned as a direct entry into the Martian atmosphere from a hyperbolic transfer orbit. A mid-latitude low elevation landing site is most probable. Communication with Earth is planned to take place by direct link with no orbiter intercept. Spacecraft power is currently envisioned as being derived from solar energy. Surface operation on the planet would include deployment of various instruments and collection of key scientific and engineering data. The objectives of the mission are to test the entry, descent, and landing methods; survival of the lander system over several day–night cycles; instrument deployment; and to determine the ability to launch a successful low cost mission.

It is planned that the MESUR Pathfinder mission will be followed by a MESUR Network proposed to start in FY 1996. The objective of this mission is to establish a global network of stations on Mars to concurrently collect and return scientific data over a minimum of one Martian year. Project planners view this type of mission as a logical evolutionary step following the Viking mission and as a precursor to sample return and/or human exploration. MESUR, as envisioned at the time of this workshop, would include up to 16 stations providing pole to pole coverage of the planet and incorporating a variety of scientific instrumentation. This network of landers would be launched on Delta vehicles in groups of four between 1999 and 2003. Communication would be accomplished using a relay orbiter.

Preliminary design concepts for the MESUR mission were described. Included was an option that involved a rover vehicle of approximately 9 kg. A tetrahedron lander configuration was presented as one potential "hard" lander concept. It was noted that the tetrahedron concept was previously conceived and tested in Russia. Entry and descent options and an entry profile were shown, including a description of the associated engineering factors.

Finally, some planetary protection working assumptions for the MESUR Pathfinder and Network missions were presented. These included the assumption that bioload reduction by dry heat would not be required. It was noted that project cost estimates are predicated on using "off-the-shelf" equipment and it is unlikely that such equipment could survive the required heating to temperatures comparable to the Viking procedures. Other assumptions were that no bioshield would be required, cleanroom assembly would be used, and dry heat treatment of selected components may be needed to meet planetary protection requirements. Concerns were expressed about the mechanisms and techniques required to provide analyses to demonstrate compliance with planetary protection constraints.

The discussion period included questions about why the MESUR mission strawman payload did not include life detection or biological experiments. The consensus was that Viking data indicated

that additional environmental data were needed to properly design such an experiment and that the MESUR missions, in combination with the Russian Mars 1994 and 1996 missions, would gather much of the needed information. Much discussion centered around the need for sample return missions. It was decided that sample return missions would probably be required to conduct the critical experiments.

Planetary Protection Options for MESUR

This study was performed in support of the MESUR Phase A effort at Ames Research Center in 1991. The objective was to analyze how MESUR could achieve Viking cleanliness levels, should those be imposed on the mission for whatever reason. This study was conducted before the NAS issued its recommendations of reduced requirements for Mars landers without life detection experiments.

The study was divided into three phases. The first evaluated the impact of imposing Viking-like requirements on MESUR, the second evaluated bioload reduction technology developed since Viking and the applicability of new techniques to spacecraft decontamination, and the third assessed various other options that could be applied to MESUR to achieve planetary protection requirements. The third phase of these efforts was the subject of this presentation.

Using Viking criteria and constraints as a baseline, it was demonstrated that MESUR would require both component and total vehicle bioload reduction to reach required levels of cleanliness. Although the analysis indicated that the level of decontamination for MESUR would be less severe than for Viking, this alone would not provide significant cost savings. It was also determined that the proposed reductions in values for probability of growth on Mars (P_g), which had been recommended by other studies (see reference on page 1), afforded little benefit in achieving Viking-like cleanliness requirements. Mission designers wishing to maintain maximum flexibility would be forced to use the most conservative P_g value (10^{-7}). This, in turn, would require that the vehicle and components be subjected to bioload reduction by dry heat to meet Viking-like cleanliness requirements.

Studies were presented that evaluated the influence of selective component decontamination procedures combined with aggressive cleaning. Study results concluded that although the level of cleanliness achieved for Viking could not be achieved, significant bioload reduction could be accomplished in this way.

In summary, the study determined that if achieving Viking cleanliness standards was required, then the MESUR vehicles would have to be subjected to dry heat bioload reduction to achieve a comparable level of cleanliness. The study further concluded that cleaning and selective decontamination of spacecraft components reduced vehicle bioload, but that the reduction was insufficient to meet Viking-like contamination constraints. It was recommended that detailed implementation techniques to achieve planetary protection constraints remain as project responsibilities and that continued efforts be expended to further evaluate burden assessment and reduction technology.

Microbes and Spacecraft Components

This session centered on organisms isolated and identified from various spacecraft materials. The quantity and type of organisms reflected the type of material tested. The results of these studies can be used to identify the susceptibility of materials to microbial contamination. Knowledge of these material properties should allow specification of the appropriate decontamination techniques and selection of those materials tailored to specific bioload reduction techniques.

Cultivation procedures for isolating organisms from spacecraft materials were conducted under various conditions using a simulated Martian environment. A detailed summary of the findings was presented, which showed the types and quantities of bacteria and fungi isolated. A few of the isolated organisms grew under anaerobic conditions. *Bacillus polymyxa* was isolated from a large percentage of the materials, and this organism was capable of growing under anaerobic conditions. Organisms capable of growing under anaerobic conditions were of the most concern for potential growth and contamination on Mars. It was also noted that viable but nonculturable organisms were probably present.

Survey of Past Bioload Reduction Technology

The methods and concepts for bioload reduction developed by NASA during the years before Viking were described. Implementation of spacecraft bioload reduction techniques began in the 1960s with the attempted decontamination of Lunar spacecraft. These early attempts were unsuccessful because of extensive hardware and equipment failures. These failures ultimately led to major research programs evaluating bioload reduction and decontamination technology and development of techniques for application to spacecraft. Processes evaluated included dry and wet heat treatment, radiation, gaseous exposure, and chemical disinfection. An evaluation of processes other than dry heat was presented, which showed specific advantages and disadvantages associated with each. These processes included radiation, thermoradiation, gaseous exposure, chemical disinfection, and self-decontaminating coatings and encapsulates. These studies ultimately led to the selection and refinement of the dry heat treatment process for Viking.

Also presented was a detailed analysis of the development of parameters for the application of dry heat to Viking. This included selection of a standard test organism; definition of burden categories of surfaces, mated and encapsulated, and their respective resistance to dry heat exposure; influence of humidity on the efficacy of the process; and thermal death rate models. These factors were necessary for implementation of the process on Viking.

Bioload Reduction Technology for Landers

Bioload reduction technology consistent with previous COSPAR requirements has been under study in Russia. These studies confirmed previous concerns by others that microbial detection technology needs improvement. The study indicated that sonication of samples or spacecraft parts could affect the detected level of contamination by as much as a factor of two. Data were presented on potential contamination levels contained on or in the surface and subsurface of a variety of

materials. The studies showed that heat and radiation treatments appeared to be the most appropriate methods for spacecraft bioload reduction. Data were presented that implied that chemical decontamination may be appropriate for use only on specific spacecraft components. The same limitations applied to gaseous decontamination techniques.

Various bioload reduction approaches including use of ultraviolet light, ethylene oxide, etc., were evaluated. The attractiveness of gaseous exposure was one of the motivating factors for studies to develop a combined process for spacecraft bioload reduction. The combined process selected for study and development was exposure of the spacecraft to a radioactive gas which could be implemented after launch of the vehicle. This technological approach provides the advantage that because the process was implemented after launch, the problems associated with recontamination were minimized or eliminated.

Data were presented on the radiation inactivation characteristics of several microorganisms isolated from several Russian spacecraft sources; several radiation resistant organisms were found. Findings indicate that radiation resistance can vary from one to ten percent of the total population. Radiation compatibility studies of many different materials, including various electronic parts and components, were discussed.

Finally, the application of this technology to the Russian 1994 and 1996 missions and advantages of its proposed use were discussed. Also included was a discussion of how this process is used to meet the COSPAR policy requirements. Data were presented on the efficacy of the process; however, the exact composition of the gas and the type of radiation were not identified because of industrial confidentiality. Lengthy discussions followed relating to electronic parts and materials compatibility and potential problems associated with the launch of radioactive gas.

Russian Mars 1994 and 1996 Missions and Planetary Protection Hardware

The Mars '94 mission consists of two small landers and two penetrators. The penetrators and landers are launched from Mars orbit and their trajectories and performance are controlled independently.

The scientific objectives of the penetrators are to collect television images of the Martian surface, meteorological data, chemical composition and water content of the soil, seismic activity, and physical and mechanical characteristics of the Martian regolith, and to determine magnetic properties. In addition, the two small lander stations will collect additional data complementing that collected by the penetrators.

A general scheme for the inflight bioload reduction technique was presented. Specific hardware configuration and operations were discussed, including a schematic showing gas penetration into the landers and penetrators and removal of the gas following exposure. Hardware that cannot withstand exposure to the decontaminating radioactive gas (i.e., parachute, critical electronic parts, etc.) will be cleaned by other methods before incorporation into and launch of the vehicle.

For Mars '96, the bioload reduction process to be used would be essentially identical to that described for Mars '94. One major difference between the missions is the presence of a large balloon on Mars '96 to be launched from the spacecraft during entry. The size, complexity, and fragility of the balloon probe requires development and application of special cleaning procedures. Detailed explanations of this process were presented. Additionally, the Mars '96 mission will contain a small rover that requires special attention to bioload reduction techniques.

Several of the critical hardware elements and materials for the missions were not completely compatible with the proposed radioactive gaseous decontamination process, and development work was continuing. The final procedures may include individual decontamination of certain components with protection against recontamination, whereas other components may require enclosure in airtight containers.

Bioload Reduction Techniques for Mars 1994 and 1996

The classical probabilistic approach to planetary protection was applied to the balloon project for the Russian Mars '96 mission. The calculated requirements were translated into the bioload reduction needed for the balloon to meet the required bioload levels at launch. Additionally, materials and system compatibility of the balloon components were addressed. In summary, it was concluded that it would be difficult, if not impossible, to achieve the required levels of cleanliness using the radioactive gas proposed for the 1994 and 1996 spacecraft. More favorable results appeared to be achieved for the balloon using gamma radiation. Under these conditions, the balloon would be housed in a sealed container and irradiated for a period sufficient to reduce the bioload to the required level. It was noted, however, that the gondola and other balloon components were not compatible with gamma radiation, and an alternate approach using hydrogen peroxide was evaluated for decontaminating these components.

Data were presented on results of testing of balloon materials compatibility with the proposed radiation and hydrogen peroxide process. Considerable work still remains to resolve bioload reduction issues for the balloon. This includes further refinement of the process focusing on additional materials compatibility studies and decontamination assurance to demonstrate compliance with planetary protection criteria. Particular concern was expressed, however, that the development of new processes and procedures may not be timely enough for use on the 1994 and 1996 missions.

DISCUSSION

The discussion focused on reviewing the SSB recommendations that landers carrying life detection instrumentation achieve at least the Viking levels of bioload reduction, and that landers not carrying life detection experiments achieve at least Viking pre-heat-treatment bioload levels. Although the workshop and its participants were not in a position of creating or formulating policy and requirements, it could make recommendations related to policy, technology, missions, etc. Therefore, the group discussed and expanded on the SSB recommendations in preparation for these recommendations being considered for incorporation into international policy.

Until the SSB's recommendations were disseminated, Mars landers were considered Category IV missions and all planetary protection evaluations, including those for MESUR and Mars '94 and '96, have assumed application of the constraints associated with this classification. Given the SSB recommendation, a scenario was visualized that could conceivably be adopted by COSPAR as policy for the future. It could be proposed that the policy be modified to include two groups under Category IV: Category IV-A, which would impose bioload reduction requirements like Viking's up to terminal heat treatment on missions without life detection experiments; and Category IV-B, which would impose full Viking bioload reduction requirements on missions that have landers with life detection experiments.

With regard to the concern that the SSB recommendations were not quantitative, it was noted that the term Viking-like bioload reduction referred to a known microbial load and, consequently, the statement in itself indicates a quantitative level of decontamination. That is, the bioload levels to be met are the number of organisms on the Viking spacecraft, either immediately before or just after terminal dry heat treatment. However, it was also felt that the term Viking-like implied the use of the classical probabilistic approach to planetary protection. This suggested the use of caution in interpretation of the term Viking-like and that, with currently accepted low values for P_g, it is conceivable this type of statement could result in overkill. On the other hand, the recommendations made by the SSB do not require the use of a P_g value. In stating Viking-like, a given level of cleanliness (e.g., number of organisms per unit area of spacecraft) is implied that is independent of a P_g calculation.

The concern that spacecraft engineers need something more quantitative than the statements proposed by the SSB continued to be debated. It was felt that the recommendations fell short of providing or identifying methods for cleaning, and, consequently, the statements made about requirements would be better understood if quantitative goals were provided rather than specifying qualitative requirements such as cleanroom assembly, etc. The SSB, however, resisted developing recommendations based on the classical mathematical approach. The starting point used for the most recent study was the 1978 SSB report that was accepted by COSPAR, and the present SSB representatives saw no need to modify the findings of that report. If quantitation was needed, the values used in that 1978 report were deemed acceptable; however, although the current SSB members felt that the value for P_g was extremely small and maybe even less than stated in the 1978 report, they resisted placing a new value on P_g.

Discussions also focused on the implication that the SSB recommendations indicate that it is acceptable to land a "dirty" spacecraft on Mars if no life detection experiment is on board. The SSB considered the probability of growth of a terrestrial organism on Mars to be extremely small. Therefore, it follows that the concern about depositing organisms on the planet is very small; however, we should be concerned about the possibility of such organisms contaminating a life detection experiment that might be carried on future spacecraft. Further, the properties of the landing site should also be considered when determining the number of organisms allowed on a vehicle and/or the level of contamination deposited on the planet. A mission-by-mission analysis may be required to answer that question. Clearly, the SSB report shifted emphasis away from protection of the planet and more toward protection of science.

The SSB also considered the possible distribution of microbial contamination on Mars by winds and other environmental factors. The consensus was that, given the harsh environmental conditions

that exist on Mars, the likelihood of an organism being redeposited at a more favorable site in a viable state was considered very remote. However, this represents an area where more study and/or modeling may be required.

Because the probability of growth of terrestrial microbes on Mars is small, why is there a need to impose any requirements at all on a vehicle that does not carry life detection experiments? This is important because although the requirements may be less severe than those imposed on life detection missions, they are not insignificant and could have considerable cost impact. In this regard, although the SSB believes the P_g to be very small, they do not state that the value is zero. Furthermore, scientists are also concerned about organic as well as microbial contamination of the planet, and controls must be imposed to ensure the integrity of scientific studies. For these reasons, some level of cleaning is required on vehicles that do not carry life detection experiments.

If landing site properties could have some effect on planetary protection requirements, then a mission such as MESUR or Mars '96, with capability for landing at multiple sites, would have to impose the strictest cleanliness controls because the project would want to maintain maximum flexibility to target specific landing sites. Clearly, this is another area needing further study. Even the 1978 SSB report was somewhat site dependent in that it specified a range of P_g values depending on where on the planet a spacecraft might be sent.

The data from the Viking experiments cannot be used to shed light on the likelihood that terrestrial organisms will grow on Mars. Therefore, although it is a radical and controversial idea, the suggestion was made that it might be scientifically interesting to deliberately contaminate Mars with a known organism. This would allow scientists to evaluate the probability of growth on Mars by looking for the presence of that organism with life detection experiments. It was suggested that such an idea would be worth discussing in more detail at a future meeting. It could also be expanded to include depositing and then measuring survival of chemical and biological marker molecules as well.

Another suggestion offered was that spacecraft components coming in direct contact with the surface of Mars be decontaminated. This would include parachutes, aeroshells, lander pads, etc. Electronic components or items in protective containers would not require such treatment since they are constructed in a highly controlled environment and would have greatly reduced bioloads. Components that could be eroded in the Mars environment should also be subjected to bioload reduction. Further, if a vehicle crash lands on the planet, that particular landing site should be excluded from future exobiological exploration because of the potential release of buried microbial contamination, which could then become detectable on a future life detection mission. Others viewed such a recommendation to be much more stringent than the SSB intended for landers not carrying life detection experiments. However, concern about transportation of contamination to other sites on Mars is valid and certainly warrants further study. In addition, if a project wished to impose requirements that were more stringent than the proposed guidelines, there was nothing to preclude such an action. However, it is unlikely that missions without life detection would require these additional bioload reductions.

CONCLUSIONS AND RECOMMENDATIONS

Following the presentations and general discussion, several conclusions and recommendations were developed. They are summarized as follows:

1. The SSB recommendations were acceptable in principle and should be ratified. In addition, some suggestions were offered as qualifications to the SSB report. For example, there was widespread agreement that the SSB recommendations need to be made as quantitative as practical in order to prevent misinterpretation by various projects, and that the source information used for this quantitation should be the Viking database. Also, the SSB recommendations need to be related to, and integrated with, existing COSPAR policy and ultimately adopted by COSPAR.

2. The SSB recommendations appear to shift the emphasis of planetary protection away from concerns about contaminating the planet to protection of exobiological science to be done on future missions. There was concern expressed that this apparent shift of emphasis could result in a biasing away from experiments and sites of exobiological interest; however, there was no recommendation on how to address this issue. This apparent shift further blurs the line delineating planetary protection from exobiological science. As an example, the planetary protection requirements for Viking were not as stringent as the science requirements, but the science requirements are often cited as the planetary protection requirements.

3. The adoption of the proposed SSB recommendations would provide significant relief to planetary protection implementation on the Mars '94 and MESUR Pathfinder missions. However, it was recognized that even these relaxed requirements will still impose some incremental impact on mission complexity and costs. There was also some concern that how the recommendations were interpreted could potentially result in increased complexity for the Mars '96 and MESUR Network missions depending on such things as how life detection instrumentation is defined, and in view of multiple landing sites planned for multiple landers (MESUR) and balloons (Mars '96). These and other considerations may require more detailed interpretation of the SSB recommendations.

4. A better definition of what constitutes a life detection instrument is clearly needed. Exobiology experiments for Mars missions could range from the detection of organics to the detection of extant and extinct life forms. However, it is unlikely that all such experiments would be considered life detection and consequently require the level of cleanliness achieved on Viking following dry heat treatment. Only experiments designed to detect extant life might require that more stringent controls be placed on the mission.

5. For landers without life detection experiments, it was recommended that the Viking cleanliness standards (bioloads) be clearly defined and used as the quantitative baseline for that type of mission. There was agreement that the qualitative recommendations given by the SSB were acceptable as guidelines for planning. These included such items as the requirements for impact prevention for orbiters and launch vehicles, cleanroom assembly, bioload reduction, bioload assessment, chemical inventory, etc. The SSB recommendations do provide increased flexibility for the projects to achieve planetary protection requirements, and there was strong consensus that the

exact methodology for achieving these requirements should reside with the agencies and projects responsible for the missions.

6. For landers with life detection experiments, there was a parallel set of recommendations. These included a definition of the Viking standards for use by the projects, including the techniques needed to achieve the required level of bioload reduction. A proposal was made for future missions that the planetary protection constraints and requirements should be driven by the science payload. Additionally, an idea was expressed that only organisms on the surface of the vehicles should be considered, but not those that might be buried or trapped between mated surfaces on the vehicle. There was also consensus that the qualitative guidelines for missions with life detection instruments were appropriate as specified by the SSB and, as for missions without life detection, that the implementation procedures and processes should remain the prerogative of the projects and agencies responsible.

7. More attention should be placed on the probability of organic contamination of the planet and its impact on exobiology studies.

8. There was concern that the SSB recommendations could result in the launch of vehicles with a higher level of contamination and that this could potentially jeopardize sites for future exobiological studies. It was suggested that sites where a spacecraft has accidentally impacted the planet be eliminated from future exobiology studies. It was also recommended that some mechanism be established to evaluate various sites of particular interest for exobiology and develop specific protection measures for them. Finally, it was recommended that the Mars '94 mission be exploited for the purpose of locating sites optimized for exobiological exploration with future missions.

9. The various planetary protection parameters used in project implementations needed review and reevaluation in light of the SSB's recommendations. For example, if the term Viking-like is to be used, then many of the parameters upon which Viking requirements were based may need further evaluation and definition.

10. It was recommended that the SSB recommendations be applied to a real mission so that actual requirements and implementation scenarios could be proposed and costed to assess their true impact on the project.

11. The planetary protection requirements presented for Mars Observer were acceptable as the standard for planetary protection requirements for future Mars orbiters.

12. There is a potential for very different interpretations of the SSB's recommendations. To some, the term Viking-like could imply use of the probabilistic approach used on Viking. To others, it can imply an identifiable and quantifiable bioload level; namely, the Viking levels, pre- and post-dry heat treatment. In the latter case, the levels of microbial contamination before and after dry heat treatment of Viking are known and documented, including the procedures used to achieve those levels.

13. Since the SSB felt that the probability of a terrestrial microorganism growing on Mars was extremely small, but not zero, it is appropriate that forward contamination concerns and requirements for vehicles without life detection experiments be reduced, but not eliminated entirely.

14. Considerable study will be needed to interpret and derive specific requirements from the SSB's recommendations. Identifying the requirements to that level of detail was beyond the scope of this workshop.

15. The SSB recommendations must be included within the agreements formulated by COSPAR on behalf of the international community. In the meantime, further evaluation of the concept of bioload reduction on spacecraft would appear warranted. Because of differences in bioload assessment techniques from country to country, it would seem appropriate in the near term to expand efforts on developing uniform detection and assessment methodology and standards. It was suggested that such studies could be conducted through joint Russian and U.S. activities and incorporate both U.S. and Russian spacecraft data as well as current knowledge on bioload assessment.

OTHER TOPICS

An additional topic for this workshop was the identification and discussion of planetary protection issues of importance for a Mars sample return mission. This session was intended to produce topics for the next in the ongoing series of U.S./Russian workshops on planetary protection, namely, a workshop on planetary protection and Mars sample return missions.

Mars Sample Return Scientific/Technology Issues

The question of indigenous life on Mars drives the entire issue of back contamination. Before the Mariner missions to Mars, there was a different perception of the likelihood of life on Mars than exists today. It was believed that Mars had water ice at the poles, an atmosphere of 85 millibars making possible liquid water, and a wave of darkening associated with vegetation. Following the Mariner and Viking missions, the potential for extant life on Mars was viewed as being quite remote. If there is extant life on Mars, it would likely be confined to specific environmental niches. In addition, it would be specifically adapted to these environmental niches and, in the absence of such niches, may not pose a threat to our biosphere. However, prudence dictates that should the opportunity exist to return samples, certain precautions and controls should be imposed.

At a meeting of the Committee on Planetary Biology and Chemical Evolution of the SSB, a question was posed regarding the potential hazards of a returned Mars sample. There was a consensus that for all practical purposes there was no chance that a Martian organism would pose a threat to the Earth's biosphere. However, when asked if it would be acceptable to return samples without planetary protection measures, there was again virtually complete agreement that it would be prudent that such measures be required for sample return missions.

Existing COSPAR sample return policy was reviewed and discussed and some extensions to these guidelines were suggested. These extensions included bioload reduction for any spacecraft component that would encounter the surface of Mars, enclosure of the spacecraft in a bioshield during launch and cruise, collection and containment of samples at ambient (Mars) conditions, breaking the chain of contact with the Mars surface, and analysis of returned samples in a containment facility on Earth (D. L. DeVincenzi and H. P. Klein: Planetary Protection Issues for Sample Return Missions. Adv. Space Res., vol. 9, no. 6, 1989, pp. 203–206).

Considerable communication with and education of the general public would need to accompany such a mission. This mission will be complicated by the well-known failed attempts at containment during the Apollo program, which can be used as an example of the potential hazard associated with sample return missions.

Sample Return Nonscientific Issues

Although the nonscientific issues may appear insignificant in the overall mission context, they can become a significant mission impediment if improperly handled. If space agencies fail to deal with social issues early in mission planning phases, it may increase the likelihood of public opposition, cost increases, and other obstacles to successful mission completion. Past experiences of the space program have been examined with the objective of identifying and prioritizing what considerations and requirements should be incorporated in mission planning activities so that forward looking recommendations can be developed for future sample return missions. It is a fact that planetary protection means something quite different to the engineers and scientists than to the general public.

Many data exist on planetary protection techniques to minimize forward contamination, although there is still considerable discussion of the methods needed to achieve the requirements. The public is generally uninvolved or uninterested in these debates, but this will not be the case with back contamination.

It is predicted that the level of public concern that might exist with back contamination issues will be significant. The prediction is based on the public's response to such issues as genetically engineered microorganisms, nuclear power, food irradiation, and various industrial processes such as mass incinerators. Public response to these issues suggests that public vigilance about risk will likely remain the same or increase. This appears to be particularly true for health and environmental issues.

It is also conceivable that programs could be delayed or canceled based on issues totally unrelated to the objective of the mission in question. One recent example of such an action was the attempt to delay the Galileo mission launch, not because of opposition to the mission, but because of an objection to radioactive materials being launched into space. Additionally, there has been a migration away from the more scientific and technical decision-making processes of the past, and an increased emphasis on the social decision-making process. This movement will force more attention on the social issues of spaceflight and less on the technical and analytical attributes of a mission. It is highly possible that such social elements could alter the course of a mission even to the extent of cancellation.

Sample return missions possess every element of the worst case scenario for social debate. When compared with some recent social challenges, such as genetic engineering, sample return missions offer a far greater opportunity for social involvement. A sample return mission extends far beyond local concerns and can quickly become an issue of international concern. Insufficient planning will likely impose significant delays and could easily force cancellation of a mission.

A variety of domestic and international laws and treaties governing the control of both forward and back contamination were also discussed. A brief explanation of each law and treaty was provided. It was pointed out that the National Environmental Policy Act ensures that information is made available to the public before program implementation.

There are many legal issues, research and development programs, management issues, and understanding of mission architecture and parameters that must be addressed soon, and appropriate funding must be provided to initiate these studies.

Topics for Sample Return Workshop

Following the presentations, a brief discussion period took place. In addition to the scientific and nonscientific considerations posed above, three other topics were also suggested for a follow-on U.S./Russian workshop on sample return missions:

1. A topic that would be of interest at such a workshop would be an evaluation of recent information regarding transfer of planetary fragments between Mars and Earth, and how this would affect concepts of planetary cross contamination. Such studies would also be of great interest and value in interpreting information from meteorites concerning the physical and chemical processes operating during the early evolution of the solar system.

2. Another topic of interest would be the research and technology developments necessary for return of a sample from Mars. Specifically, such developments include aseptic Mars sample transfer technology, remote spacecraft exterior surface decontamination techniques, sample containment and preservation technology, etc. Collaborative efforts between the U.S. and Russia would be extremely useful in defining many of these technology needs.

3. It is highly likely that the methods and protocols that would be used for quarantine analyses of returned Mars samples today would be quite different from those used in the past for returned lunar samples. A joint effort to discuss and define these techniques would be most valuable.

APPENDIX 1

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APPENDIX 2

WORKSHOP AGENDA

Monday, July 13, 1992

8:30 a.m.	Introductions, Welcome, Logistics	Various
9:00	Workshop Objectives and Products	Ivanov and DeVincenzi
9:30	Ancient Life/Chemical Evolution on Mars	DesMarais
10:00	Extant Life on Mars	Ivanov
10:30	Existing NASA/COSPAR PP[3] Policy	Rummel
11:00	Space Studies Board Recommendations	Young
11:30	Discussion – Scientific and Policy Issues	All
12:00	Lunch	
1:00 p.m.	PP Implementation for Viking Orbiters	Daspit
1:30	PP Requirements for Mars Observer	Rummel
2:00	Discussion – PP for Future Mars Orbiters	All
2:30	PP for Viking Landers	Daspit
3:10	MESUR/Pathfinder Mission Design and PP Issues	McNamee
3:50	PP Options for MESUR	Howell
4:30	Discussion – U.S. Mars Missions	All
5:30	Adjourn	

[3]Planetary Protection.

Tuesday, July 14, 1992

8:30 a.m.	Microbes and Spacecraft Components	Victorov
9:00	Survey of Past Bioload Reduction Technology	Stabekis
9:30	Bioload Reduction Technology for Landers	Trofimov
10:30	Russian Mars 1994/1996 Missions and PP Hardware	Bogomolov
12:00 p.m.	Bioload Reduction Techniques for Mars 1994/1996	Debus
12:30	Lunch	
1:30	Discussion – Recommendations for PP for Landers with and without Life Detection; Recommendations for New Research and Technology Development	All
5:30	Adjourn	

Wednesday, July 15, 1992

8:30 a.m.	Development of Workshop Final Recommendations	All
10:00	Mars Sample Return Scientific/Technology Issues	Klein
10:30	Sample Return Nonscientific Issues	Race
11:00	Topics for Sample Return Workshop	All
12:00	Adjourn	

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13. ABSTRACT *(Maximum 200 words)*

A workshop was convened to discuss the subject of planetary protection implementation for Mars lander missions. It was sponsored and organized by the Exobiology Implementation Team of the U.S./Russian Joint Working Group on Space Biomedical and Life Support Systems. The objective of the workshop was to discuss planetary protection issues for the Russian Mars '94 mission, which is currently under development, as well as for additional future Mars lander missions including the planned Mars '96 and U.S. MESUR Pathfinder and Network missions.

A series of invited presentations was made to ensure that workshop participants had access to information relevant to the planned discussions. The topics summarized in this report include exobiology science objectives for Mars exploration, current international policy on planetary protection, planetary protection requirements developed for earlier missions, mission plans and designs for future U.S. and Russian Mars landers, biological contamination of spacecraft components, and techniques for spacecraft bioload reduction. In addition, the recent recommendations of the U.S. Space Studies Board (SSB) on this subject were also summarized.

Much of the discussion focused on the recommendations of the SSB. The SSB proposed relaxing the planetary protection requirements for those Mars lander missions that do not contain life detection experiments, but maintaining Viking-like requirements for those missions that do contain life detection experiments. The SSB recommendations were found to be acceptable as a guide for future missions, although many questions and concerns about interpretation were raised and are summarized in this report. Significant among the concerns was the need for more quantitative guidelines to prevent misinterpretation by project offices and better access to and use of the Viking data base of bioassays to specify microbial burden targets. Among the questions raised were how will the SSB recommendations be integrated with existing Committee on Space Research (COSPAR) policy and how will they apply to and affect Mars '94, Mars '96, MESUR Pathfinder, and MESUR Network missions?

One additional topic briefly considered at the workshop was the identification of some issues related to planetary protection considerations for Mars sample return missions. These issues will form the basis for a follow-on joint U.S./Russian workshop on that subject.

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